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ON THE HEIGHT OF AURORAL ABSORPTION

by

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ABSTRACT

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The height distribution of the absorption produced by two different observed electron spectra, $N(E)dE = 5.10^{9} \exp(-E/5)\, dE$ and $N(E)\, dE = 7.10^{4} \exp(-E/41)\, dE$ and also by the bremsstrahlung from the first mentioned one has been estimated. The results indicate that the absorption in the 60-90 km range, due to hard electron spectra, often may dominate, whereas the absorption caused by bremsstrahlung is smaller than that due to the primary electrons producing the x-rays. These results are discussed in respect to the height of the absorbing layer and the observed very small variation of auroral absorption at sunrise and sunset.

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INTRODUCTION

It was found in an early stage of the experimental investigation of the ionosphere by means of ionosondes that during aurora total blackout of the ionosonde often occurs, indicating strong absorption taking place below the reflecting layers. That the main part of the ionization producing the radiowave absorption that is characteristic for magnetically disturbed conditions in the auroral zone is located below the E-layer is evidenced also by several other observations. The few rockets containing electron density experiments that have been flown into the disturbed ionosphere in the auroral zone have all brought down information showing that absorption takes place well below the E-layer. Heikkila and Penstone (1961), for instance, found a pronounced peak in the height distribution of absorption per unit length at 75 km and no measurable absorption at all above 90 km. The rocket measurements of Seddon and Jackson, Kane and others (cf. e.g. Seddon and Jackson, 1958, and Kane, 1963) seem not to have given any results showing so high electron density up in the E-layer that the main part of the absorption might have taken place there. The Norwegian rocket measurements of electron density in the lowest ionosphere have shown strong increases in electron density in and below the normal D-layer height interval during aurora and magnetic storms (cf. Jespersen et al., 1963) Multifrequency riometer measurements often give equivalent heights below 75 km for the absorbing ionization (Ziauddin, 1963) and the time constants evaluated from absorption records indicate similar altitudes (Ziauddin, 1961a; Gustafsson, 1963). Furthermore, electron density profiles obtained from partial reflection and cross modulation studies in the auroral zone show strong increases in the electron density, and the absorption caused by it, below 80 km during aurora and magnetic storms.

Some of the observational facts mentioned above led Chapman and Little (1957) to propose that bremsstrahlung x-rays, produced by the primary auroral electrons, are responsible for the major portion of the auroral absorption. However, the absorption caused by bremsstrahlung from primary auroral electrons, of the spectra observed by McIlwain (1960), is probably considerably less than that due to the primary electrons themselves (cf. Aikin and Maier, 1963, and below). Practically all the primary electrons found by McIlwain will be stopped above 80 km and most of the absorption takes place above 90 km.

Investigations of the variation of auroral absorption in the twilight periods (Hultqvist, 1962, 1963; Brown and Barcus, 1963; Holt and Landmark, 1963) have shown that the difference between post-sunrise and pre-sunset (day) absorption on one hand and pre-sunrise and post-sunset (night) values on the other hand is much less than expected on the basis of the present knowledge about the negative ions in the lowest ionosphere. The two most probable alternative interpretations of this observation have been proposed to be the following: either the main part of the ionization responsible for the auroral absorption is situated above 90 km altitude or the ratio of negative ion to free electron densities, λ , is much less than hitherto believed (Hultqvist, 1963b).

Campbell and Leinbach (1961) have calculated the absorption taking place in the height interval of the visual aurora from measured fluxes of auroral light and the ratio of ionization and excitation cross-sections. They proposed that sometimes all auroral absorption may take place in the height interval where the visual form is located. On the basis of this and the absence of day-night variation in auroral absorption, Brown and Barcus (1963) concluded that auroral absorption usually takes place above 90 km altitude. This first one of the two above mentioned alternatives means, however, that all the observational evidence mentioned earlier for a low altitude of the absorbing ionization should be disregarded. This seems not very probable to this author.

While the rocket-measured auroral electron spectrum of McIlwain (1960) was very soft and produced the ionization mainly up in the altitude range of visible aurora (see below), some rocket experiments in the auroral zone have shown considerably harder electron-spectra. Davis et al. (1960) found the differential energy spectrum to be proportional to E^{-2}, while McDiarmid et al. (1961) observed an exponential spectrum with mean energy of 22 kev. In addition to these few isolated rocket observations of harder electron spectra, there is now available results of satellite observations of similar high-energy electrons, obtained during many passages through the auroral zones (Mann et al., 1963). These observations support the low altitude absorption alternative. They will be discussed in this note and will first be briefly described.

OBSERVATIONS OF FLAT ELECTRON SPECTRA IN THE AURORAL ZONE

Mann, Bloom and West (1963) flew magnetic spectrographs, covering the energy range 90-1200 kev for electrons in the Discover Satellites nos. 29 and 31. These satellites were launched on August 30 and September 17, 1961, respectively, in near polar orbits. Discoverer 29 had a perigee of 160 km near the North Pole and an apogee of 610 km. The perigee of 240 km was at 30°N for Discover 31 and its apogee was at 420 km. The opening angle of the instrument was small (about 2X4 degrees) and it was continuously directed outward along the radius vector from the earth's center.

Three different types of differential electron spectra were found. One proportional to exp (-E/5 kev), i.e. the same as found by McIlwain (1960), was observed over the polar caps and sometimes down to rather low latitudes, especially in the northern hemisphere. The fluxes of these steep spectrum electrons were sometimes 10-100 times greater than that found by McIlwain (1960) to be associated with a weak aurora of international brightness coefficient (IBC) about I. The differential energy spectrum obtained by McIlwain was:

$$N(E) = 5.10^{8} \exp(-E/5 \text{ kev}) \text{ electrons cm}^{-2}\text{sec}^{-1}\text{ster}^{-1}\text{kev}^{-1} \quad (1)$$

In the calculations below a ten times more intense flux will be employed.

A second type of spectrum was observed only in the region of the South-Atlantic magnetic anomaly and could be interpreted as the lowest tail of the

VanAllen belt

The third type of spectrum observed is the one that is of most interest here. It was a class of harder electron spectra than that reported by McIlwain in (1960), predominantly found in the auroral zones. These electrons were observed when the spectrometer looked within 10-20 degrees of the geomagnetic field lines. This indicates that the electrons were injected into the atmosphere. They were probably primary auroral electrons, according to Mann et. al. (1963).

The spectra of this kind observed during 20 different passages through the auroral zones could be grouped into two classes with regard to energy fall-off: one given by $N_o e^{-E/25 \text{ kev}}$ and the other by $N_o e^{-E/42 \text{ kev}}$. Some of the spectra, however, had e^{-1} energy values as low as 15 kev and in one case a high value of 165 kev was found.

The calculations below will be made for a differential electron energy spectrum of

$$N(E) = 7.10^4 \exp(-E/41) \text{ electrons cm}^{-2}\text{sec}^{-1}\text{ster}^{-1}\text{kev}^{-1} \qquad (2)$$

obtained from Fig. 5 in the report of Mann et. al. (1963).

There was a magnetic storm when Discoverer 29 was in orbit and it was mainly in the course of that storm that the hard electron spectra were observed in the auroral zones. There was probably a time lag between the start of the storm and the onset of the electron bombardment, but due to incomplete orbit coverage nothing definite could be stated. The electron flux definitely diminished as the storm waned.

ABSORPTION PRODUCED BY PRIMARY AURORAL ELECTRONS, GENERAL

The exact calculation of the energy dissipation of fast electrons in the atmosphere is very complicated because of the range straggling due to large single-energy losses occurring in both radiative and inelastic collisions and also because of the large angular deviations encountered by the electrons in elastic collisions. Even the extensive numerical calculations of Spencer (1959) give somewhat inaccurate results for large thicknesses of the absorbing material.

Maeda (1963) has given the following empirical relation for the attenuation of electrons with energies between 5 and 300 kev:

$$N(E,x)\, dE = N_o(E) \exp(-0.318.10^7 E^{-2.2} x)\, dE \tag{3}$$

where $N_o(E)$ is the initial differential intensity of electrons with a kinetic energy of E, and x is given in g/cm^2. This expression is based on laboratory measurements and takes into account elastic scattering. As soon as an electron has undergone interaction, so its energy is outside the interval dE at E, it is considered as lost from the beam. In using expression (3) for calculation of the energy dissipation, one thus considers the total energy of an electron that has been inelastically scattered at an atmospheric depth, x, as dissipated at that same depth. This gives some overestimation of the energy dissipation at small atmospheric depths and thus produces the ionized layer at somewhat too high an altitude in the atmosphere. On the other hand, since the electron flux is certainly not attenuated in an exponential way close to the electron range, it seems likely that an overestimation is made also of the very lowest part of the produced ionization, when formula (3) is employed. It is, however, probable that the errors in the height distribution of the produced ionization are not large, measured in km, in the atmosphere where the density increases approximately exponentially with decreasing height. More on this in the discussion on page 11.

Expression (3) has the great advantage of making all calculations easy. It will be used below for the estimates of the absorption caused by various electron spectra. The geomagnetic field lines will be assumed to be vertical in the auroral zones.

The flux of electrons with a pitch angle α at the atmospheric depth x g/cm^2 is then given by

$$2\pi N(\alpha, x, E)\, dE \sin\alpha\, d\alpha = 2\pi N_o(E,\alpha) \exp(-x/\sigma(E) \cos\alpha) \sin\alpha\, d\alpha\, dE \tag{4}$$

where $1/\sigma$ (E) = $0.318.10^7$ $E^{-2.2}$ and $N_o(E, \alpha)$ is the differential electron spectrum outside the atmosphere. Based on the experimental results reviewed above, it will be assumed that the low energy spectrum ($\propto \exp(-E/5)$) is isotropic over the upper hemisphere, but that the high energy electrons ($\propto \exp(-E/41)$) come in only within one steradian around the field lines, and they will be assumed to propagate vertically.

(a) Isotropic flux:

Integrating the pitch angle from 0 to $\pi/2$ and substituting $y = x/\cos\alpha$ we obtain

$$N(x,E)dE = 2\pi N_o(E)\ G(x/\sigma(E))\ dE \tag{5}$$

where $G(x/\sigma\ (E))$ is the so-called Gold integral (cf. e.g. Rossi, 1952):

$$G(x/\sigma\ (E)) = \int_1^\infty e^{-xs/\sigma\ (E)}\ s^{-2}\ ds. \tag{6}$$

$$dN(x,E)/dx = 2\pi N_o(E) \cdot dG/dx = 2\pi\left[N_o(E)/\sigma\ (E)\right]\ Ei(-x/\sigma\ (E)\ ) \tag{7}$$

where $Ei(-x/\sigma\ (E)\ )$ is the exponential integral, defined by

$$-Ei(-y\ ) = \int_y^\infty e^{-z}z^{-1}dz\ . \tag{8}$$

The energy dissipation rate to the atmosphere per unit volume by electrons of energy E is given by

$$-\ \rho(h)E\ .\ dN(E,x)/dx = 2\ \pi\ \rho(h)E\left[N_o(E)/\sigma(E)\right]\ \ Ei(-x/\sigma\ (E)\ )\ \text{kev cm}^{-3}\ \text{sec}^{-1}\ \text{kev}^{-1} \tag{9}$$

when E is measured in kev and h is the altitude in cm. By taking the average amount of energy used in production of one electron-ion pair equal to 32 ev, $N_o(E) = 5.10^9$ $\exp(-E/5)$ electrons $cm^{-2}sec^{-1}ster^{-1}kev^{-1}$ and $1/\sigma$ (E) = $0.318.10^7E^{-2.2}$, we obtain the electron production rate q(E,h):

$$q(E,h) = -3.12.10^{18}\cdot\ \rho(h).E^{-1.2}e^{-E/5}.Ei(-0.318.10^7E^{-2.2}\cdot x)\ (\text{cm}^3\ \text{sec kev})^{-1} \tag{10}$$

$-Ei(-x)$ goes to infinity when x goes to zero. The expression (10) is valid when the isotropic flux outside the atmosphere has infinite extension in the horizontal plane. In practice this means that the auroral electron bombardment must be homogenous over areas several hundred kilometers in extension for (10) to give correct results for small atmospheric thicknesses. This condition is certainly not fulfilled in most auroras. However, it only influences the dissipation in the highest layers of interest, making the electron density larger. The absorption is in any case small there. In the height interval where most of the energy dissipation takes place expression (10) should be accurate from that point of view.

(b) Vertical incidence:

For vertical incidence the expression for the energy dissipation rate to the atmosphere per unit volume by electrons of energy E is given by

$$-E\cdot dN(E,h)/dh = \varsigma(h).E.\left[N_o(E)/\sigma(E)\right]\cdot e^{-x/\sigma(E)} \text{ kev } (\text{cm}^3 \text{ sec kev})^{-1} \tag{11}$$

and the electron production rate, q(E,h), for $N_o(E) = 7.10^4\ e^{-E/41}$ electrons $\text{cm}^{-2}\text{sec}^{-1}\text{kev}^{-1}$, by

$$q(E,h) = 0.695.10^{13}\cdot\varsigma(h)\cdot E^{-1.2}.e^{-E/41}.e^{-0.318.10^7.E^{-2.2}.x} \tag{12}$$

$$\text{electrons } (\text{cm}^3 \text{ sec kev})^{-1}.$$

ABSORPTION DUE TO PRIMARY AURORAL ELECTRONS AND BREMSSTRAHLUNG

With the use of equation (10) the electron production rate q(E,h), due to a steep spectrum of McIlwain's type but with a ten times higher flux (as found by Mann et. al., 1963; it corresponds to an aurora of IBC II) was computed for every 10th kev from 5 kev up to 65 kev, and for every 10th km between 70 and 130 km. The total electron production rate due to the complete spectrum was obtained by numerical integration.

The stationary state electron density, N_e, was derived from

$$N_e(h) = \left[q/(1+\lambda)\cdot(\alpha_d+\lambda\alpha_n)\right]^{\frac{1}{2}} \tag{13}$$

The λ profiles used by Nicolet and Aikin (1960), Aikin (1962) and others, and the values $\alpha_d = 4.6.10^{-7}$ cm^3 sec^{-1} and $\alpha_n = 10^{-7}$ cm^3 sec^{-1} for the dissociative (α_d) and ion-neutralization (α_n) recombination coefficients have been used. Finally the absorption per km height interval was computed for the riometer frequency 27.6 Mc/s in the auroral zone, using the old Appleton-Hartee expression

$$dA/dh = 0.459\ .\ 10^5\ .\ N_e\nu\ /(3.34\cdot10^{16} + \nu^2) \quad (\text{db/km}). \tag{14}$$

Computations were made for the two electron collision frequency profiles shown in Figure 1. ν -profile no. 1 is probably

Fig. 1

more representative for the actual ionospheric situation at the lower heights, where it is based on recent measurements (Holt, 1963). With the use of ν-profile no. 2 in Fig. 2, absorption-per-km values higher by a factor of about two is obtained and the ratio between the high-altitude and low-altitude absorption contributions is also a little changed, but the differences are not of major importance here. Below, only the results obtained with the use of ν -profile no. 1 will be presented. The probable inaccuracy of the numerical absorption values will be discussed in some more detail later.

The result of the computations is shown as curves nos. 1 in Fig. 2a (for daytime) and 2b (for night). The total absorption amounts to 1.0 db in the day and to 0.9 at night. dA/dh has its maximum at about 90 km during the day and at

Fig. 2 a,b

95 km by night. Most of the absorption takes place above 90 km.

Aikin and Maier (1963) have calculated the electron production rate due to the bremsstrahlung resulting from the electron spectrum measured by McIlwain (1960) during an aurora of IBC I. Their electron production rates, multiplied by a factor of ten to make them correspond to the absorption given by curves nos. 1 in Fig. 2 have been converted into absorption per km in the way described above. The result is shown as curves nos. 2 in Fig. 2, a and b.

The total daytime absorption due to bremsstrahlung amounts to 0.27 db, or about ¼ of the absorption produced by primary electrons. It has its maximum at about 60 km. The thickness of the layer at its half value points is 17 km. At night the total bremsstrahlung absorption is very small, 0.06 db, i.e. about 1/15 of the corresponding absorption due to primary auroral electrons.

Finally the absorption due to the hard electron spectrum $N(E)\,dE = 7.10^4 \exp(-E/41\ \text{kev})\,dE$, observed by Mann et. al. (1963) has been computed using expression (12) for the electron production rate and the same procedure as described earlier for transferring $q(E,h)$ into dA/dh. The result is shown in Fig. 2, a and b, as curves nos. 3. The integration was carried out between 50 and 300 kev. For the spectrum above, electrons with energies less than 50 kev give negligible contribution to the absorption.

The total day-time absorption was found to be 1.9 db and the night-time one 0.5 db. The height of maximum dA/dh was 70 km in the day and a little less than 80 km at night. Thus the absorption in the 60 to 90 km height interval, due to the hard electrons, is twice as large as that due to the soft ones and one order of magnitude greater than that produced by bremsstrahlung in the day.

DISCUSSION

The uncertainty in the numerical values presented in Fig. 2 is large. The inaccuracy in the knowledge of the collision frequency introduces a possible error in the absorption of a factor of two or even more at the highest levels shown in the figure. The density in the upper half of the altitude range in Fig. 2 may vary appreciably with local time and season. This together with the low degree of accuracy in the existing experimental density values for this region, makes an uncertainty of a factor of two possible. In addition, the use of the classical magnetoionic formula result in values of dA/dh which, in certain atmospheric depths, may be 50% too low (cf. e.g. Hultqvist, 1963c).

It has been mentioned above that the calculation of the electron production rate due to an isotropic electron flux presumes a very large extension of the area of electron influx into the atmosphere. The area should be so large that electrons entering at almost horizontal direction at one side are stopped after having travelled a small part of the distance to the other side. That means that the dimensions of the area of electron influx has to be many hundred kilometers. It is certainly not true in nature that the electron flux is homogeneous over such areas. It is known, for instance, that the correlation of auroral absorption records decreases to 0.5 for a distance between the riometers of 300-400 km (Holt et al., 1961). The result of the assumption is that the absorption in the upper levels is overestimated. However, the influence on the total radio wave absorption is probably quite small, as the absorption at fairly great atmospheric depths dominates strongly. The effect on the altitude of the absorbing layer of using the simple expression (3) is certainly more important.

It has been shown by Young (1956) that the average energy lost per electron by a beam of electrons of energies from a few kev to a few ten kev in traversing an absorber is approximately equal to the energy, E_o, of an electron with an end-point range equal to the absorber thickness. This was used by McIlwain (1960) in deriving the spectrum of the electrons observed by him in aurora. McIlwain pointed out that if the integral number energy spectrum can be represented by a function of the form c exp(-E/b) where c and b are constants, then the energy flux emerging from an absorber with an electron end-point range energy of E_o will be cb exp $(-E_o/b)$. Using this and the empirical relations between energy and practical range, R, for mono-energetic low-energy electrons by Katz and Penfold (1952), the following expression can be derived for the electron production rate, q(h) (el./cm^3sec), due to an electron flux which is isotropic outside the atmosphere

$$q(h) = \frac{2\pi c}{0.032} \cdot \rho \cdot \int_0^{\pi/2} \frac{Eo(\theta)e^{-\frac{Eo(\theta)}{b}} \sin\theta \; d\theta}{R(\theta) \cdot \left[2.853 - 0.191 \ln E_o(\theta)\right]} \tag{15}$$

where $R(\theta)$ can be taken equal to 1.36 $p_{mmHg}/\cos\theta$ for the height interval of interest here. Numerical calculations have shown that the equilibrium electron density due to the soft spectrum $n(E) = 5.10^{9} e^{-E/5}$ electrons/cm^{2}sec ster kev obtained with the use of (15) differs by less than 50% from those found by means of Maeda's (1963) formula (3), except at the bottom of the ionized layer (90 km) where the difference amounts to almost 100%. Those results indicates that the use of Maeda's attenuation formula is not probable to involve errors in the absorption per unit height interval larger than a factor of two in any part of the height interval of interest,except possibly in the very low tail. The effect of this on ratios between total absorption due to various sources or on day to night ratios is probably small compared with other uncertainties.

An assumption of infinite extension in the horizontal plane of the area of electron influx was also made by Aikin and Maier (1963) in their calculation of the ionization produced by bremsstrahlung. Since the bremsstrahlung photons can travel very far in almost horizontal direction in the upper levels of interest here, the required extension of the area of influx is still higher than for the electrons. The effect of this assumption is probably that the calculated ionization rate, due to bremsstrahlung, is too high. It is difficult to give quantitative values of this overestimation. In addition to this uncertainty in the calculation of the bremsstrahlung ionization rate, there are errors introduced by the specific approximations and simplifications made by Aikin and Maier in deriving the expressions for the x-ray flux and its absorption in the atmosphere.

The conclusion of this discussion of the accuracy of the absorption values given in Fig. 2 is that only the order of magnitude is significant. The ratios of the absorption values for the various ionization sources and for the highest and lowest altitudes in Fig. 2 are probably correct within a factor less than four.

With the uncertainties in some of the parameters, of the order of magnitude mentioned, extensive calculations giving high degree of accuracy in other parameters, seem not to be justified. It may be of interest to mention that an absorption height distribution calculated on the assumption that the electron flux consists only of the electrons within one steradian around the field line direction, propagating strictly along the field lines, instead of being isotropic over 2π steradians, is only about 50% smaller than that obtained with isotropic flux. The heights of the absorbing layers and the shapes are similar in both cases. It is therefore quite reasonable to make the simplifying assumption of vertical influx for a rough estimation.

(2) It can be seen in Fig. 2 that the absorption deep in the atmosphere, due to bremsstrahlung, is probably much less than that produced mainly above 85 km by the primary electrons, for the steep electron spectra found by McIlwain. For decreasing steepness of the electron spectrum one would expect an increasing importance of the absorption produced by bremsstrahlung because of the increasing cross section for bremsstrahlung production with electron energy. On the other hand, when the primary electrons become more energetic, they ionize lower down in the atmosphere; the height difference between the ionized layers produced by primary electrons and the bremsstrahlung decreases and with it the difference in absorption cross section for the electrons in the two layers. This tends to make the bremsstrahlung less important. More calculations for various spectra are needed before a general statement about the importance of the bremsstrahlung in producing radio-wave absorption can be given, but it seems probable that the high altitude absorption due to primary electrons - and to heavey auroral particles - is greater than the absorption produced by bremsstrahlung for all spectra of interest.

(3) For the parameter values used in the calculations leading to the curves 1 and 2 in Fig. 2a and b, we expect 1 db absorption at 27.6 Mc/s for an aurora of IBC II. To obtain the corresponding absorption values for the same electron

energy spectrum for IBC I we only have to divide by the square root of ten, as there is a factor of ten for the light emmission, and therefore for ionization rate, between each IBC value. Thus an IBC I aurora (in the night) would only give 0.3 db due to primary electrons and 0.02 db due to bremsstrahlung for a McIlwain spectrum. For an IBC III aurora the corresponding values would be 3 db and 0.2 db, respectively. An IBC IV aurora, finally, would give 10 db due to primary electrons and 0.6 db because of bremsstrahlung.

(4) Fig. 2 shows that the absorption produced at low altitudes by the flat electron spectra observed by Mann et. al. (1963) may be more important than that due to the very steep spectra, also observed by Mann et. al. as well as by McIlwain. The data published by Mann et. al. (1963) do not give too much information about the range over which the hard electron flux varies. Comparison of curve 3 in Fig. 2 and the absorption to be expected for auroras of various IBC, produced by electrons with spectra of McIlwain's type, show that the daytime absorption under curve 3 dominates over that due to low energy electrons for IBC I and II (Fig. 2 illustrates the situation for an IBC 2 aurora) but not for III and IV. For night-time (Fig. 2b) the absorption due to high energy electrons is greater than that produced by the low energy ones only for IBC I aurora (with the hard electron flux unchanged), while for IBC II it is somewhat smaller. It seems, however, reasonable to assume that also the flux of electrons with flat spectrum varies at least a factor of ten up and down from that used in this note, and that its daily average value is correlated with the daily flux of steep spectrum electrons. That this is so is supported by the results of balloon observations of x-rays. The absorption due to these high energy electrons will then be the dominating one in the average.

Even if there should exist a statistical relation between the fluxes of steep-spectrum and flat-spectrum electrons, it is most probable that wide variations in the resulting total spectrum can be found from one aurora to another. One can expect to see both auroras (weak ones) without appreciable absorption and strong absorption without visible aurora. Such combinations can be obtained from the two spectral types dealt with in this note. The dissimilarity between the diurnal variation curves for visual aurora and auroral absorption may be understood on this basis.

From the report of Mann et. al. (1963) one does not get information about the occurrence frequency of the two above-mentioned types of spectra. The data from Injun I show that the radio-wave absorption is well correlated with the flux of electrons of energy greater than 40 kev (Maehlum and O'Brien, 1963). This, as well as the good correlation between radio-wave absorption and fluxes of bremsstrahlung x-rays of energies up towards 100 kev, indicates that auroral type of absorption is not primarily caused by electrons with the very steep spectrum found by McIlwain (1960). The rocket observation of Heikkila and Penstone (1961), on the other hand, can be understood as an effect of a flat electron spectrum without any contribution from the steep type.

(5) The day to night ratio of the absorption, A_D/A_N, obtained from Fig. 2, a and b, is, for absorption due to low energy electrons alone, 1.12; for the absorption produced by bremsstrahlung, 4.4; for absorption due to low energy electrons and bremsstrahlung, 1.34; for high energy electron absorption, 3.7; and finally, for the sum of absorption caused by low and high energy electrons and by bremsstrahlung, 2.2.

The observed A_D/A_N value for auroral absorption is between one and two (1.1 - 1.2 according to Hultqvist, 1962, 1963; about 1 according to Brown and Barcus, 1963, about 2 according to Holt and Landmark, 1963). Probably it is fairly close to unity.

The absorption values shown in Fig. 2 were calculated with the use of the height distribution of λ (the ratio between negative ion and free electron densities) used by Nicolet, Aikin and others in the last few years.

Of the A_D/A_N values obtained from Fig. 2, which were given above, only the "low energy electron" one agrees with the observed value of A_D/A_N. The experimental values of A_D/A_N were obtained by averaging over all auroral absorption events recorded over extended periods of time (3½ years in Hultqvist's case).

It was mentioned earlier that there is experimental evidence showing that auroral absorption is usually not caused by low energy electrons alone. When assuming equal probability of occurrence of the steep and flat electron energy spectra, which seems to be a reasonable assumption in absence of detailed statistical data, one would expect an A_D/A_N value of more than two, as mentioned earlier.

It should be mentioned here that the large uncertainty in the absolute absorption values does not affect the A_D/A_N ratio too much. The A_D/A_N value is more dependant on the height distribution. The larger the fraction of the total absorption that takes place above 90 km, the smaller the A_D/A_N value will be. From the discussion earlier, it can be concluded that it is more probable that the calculated high-altitude absorption is overestimated than that it is too small.

On the basis of what has been said above, it seems possible to conclude that there is a significant discrepancy between the A_D/A_N values calculated on the basis of the λ profiles of Nicolet and others, on the one hand, and the observed values on the other. This means that the observed absence of day-night variation in auroral absorption is <u>not</u> due to the main part of the absorbing ionization being located above 90 km. The second alternative mentioned in the introduction - that of the λ profiles being lower than believed before - is therefore supported by the results discussed in this note.

FIGURE CAPTIONS

Fig. 1. The electron collision frequency, ν, as function of altitude. Curve 1 has been drawn on the basis of data presented by Holt (1963) for the lower half of the altitude range. In the upper half curve 1 has been extrapolated so that it parallels the curve shown by Ratcliffe and Weekes (1960) in about the same way as in the lower altitudes. Curve 2 is after Nicolet (1959) below 90 km and after Hanson (1961) above 100 km.

Fig. 2. (a) is for daytime and (b) for night. Curves 1 in (a) and (b) show the height distribution of the absorption produced by the differential energy spectrum $N(E) = 5.10^9\ e^{-E/5\ \mathrm{kev}}$ electrons $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}\ \mathrm{ster}^{-1}\ \mathrm{kev}^{-1}$. The total absorption values corresponding to curves 1 amount to 1.04 db in the day and to 0.89 db at night. Curves 2 give the absorption due to the bremsstrahiung of the same electron spectrum. Total absorption in the day is 0.27 db and in the night 0.061 db. Curves 3, finally, represent the absorption distribution produced by the differential energy spectrum $N(E) = 7.10^4 e^{-E/41\ \mathrm{kev}}$ electrons $\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}\ \mathrm{kev}^{-1}$, coming in along the field lines.

Total daytime absorption is 1.9 db and the nightime one is 0.52 db.

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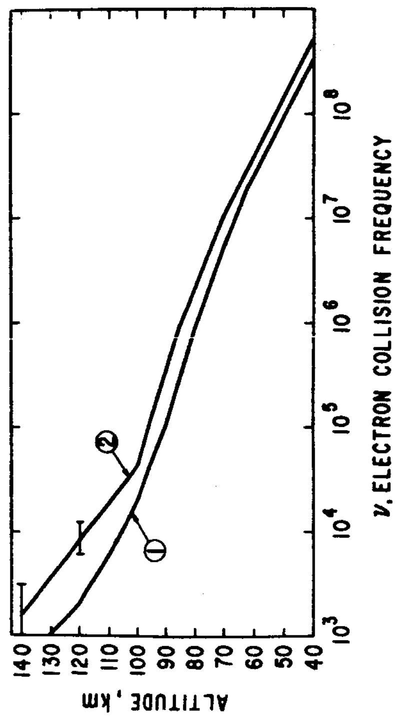

Figure 1. The electron collision frequency, ν, as a function of altitude. Curve 1 has been drawn on the basis of data presented by Holt (1963) for the lower half of the altitude range. In the upper half curve 1 has been extrapolated so that it parallels the curve shown by Ratcliffe and Weekes (1960) in about the same way as in the lower altitudes. Curve 2 is after Nicolet (1959) below 90 km and after Hanson (1961) above 100 km.

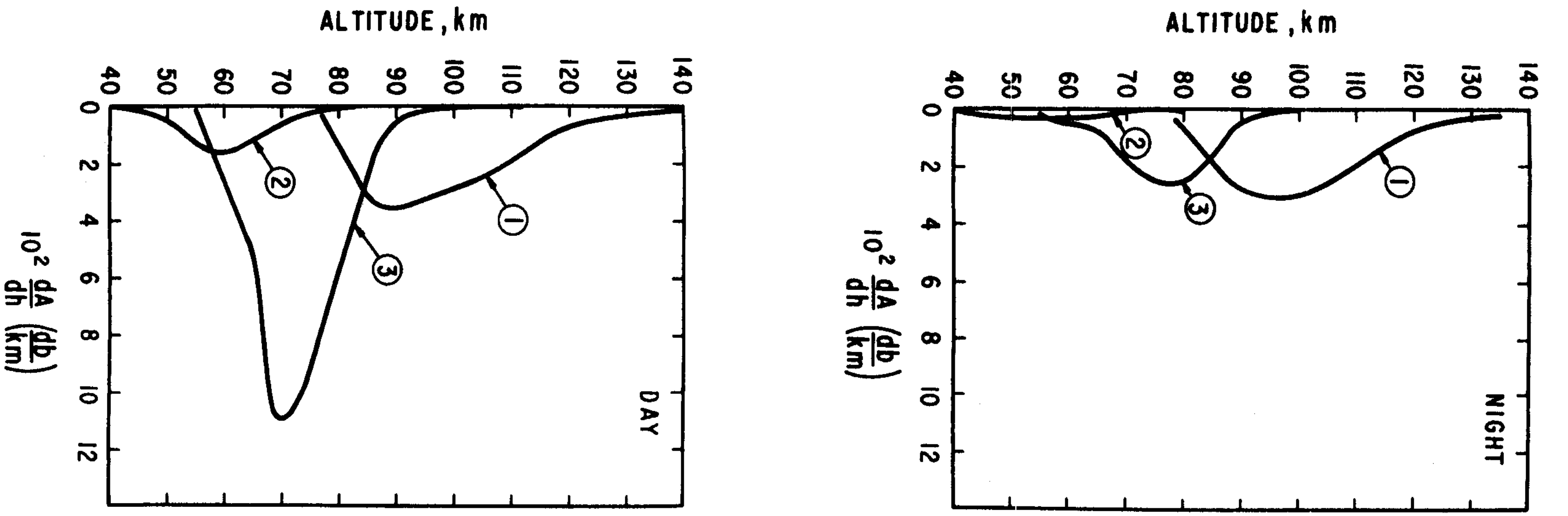

Figure 2. (a) is for daytime and (b) for night. Curves 1 in (a) and (b) show the height distribution of the absorption produced by the differential energy spectrum $N(E) = 5.10^9 e^{-E/5\ kev}$ electrons cm^{-2} sec^{-1} $ster^{-1}$ kev^{-1}. The total absorption values corresponding to curves 1 amount to 1.04 db in the day and to 0.89 db at night. Curves 2 give the absorption due to the bremsstrahlung of the same electron spectrum. Total absorption in the day is 0.27 db and in the night 0.061 db. Curves 3, finally, represent the absorption distribution produced by the differential energy spectrum $N(E) = 7.10^4 e^{-E/41\ kev}$ electrons cm^{-2} sec^{-1} kev^{-1}, coming in along the field lines.

Total daytime absorption is 1.9 db and the nighttime one is 0.52 db.

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